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Controlling Downy Mildew of Lettuce

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SUMMARY

1. Lettuce, the most important vegetable forcing crop grown in Iowa, is in some seasons seriously damaged by a disease known as downy mildew.

2. Continued periods of cloudy weather, which often prevail during the forcing season in this section, are highly conducive to the growth and development of the mildew.

3. Wild lettuce plants often afford a breeding ground for the disease. They are, therefore, likely to prove a source of infection and should be destroyed in the vicinity of forcing houses.

4. This downy mildew is primarily a seedling disease. Control measures, to be effective, must be focused upon the seedling stage of the plant.

5. Bordeaux mixture of the standard formula, 4-4-50, is recommended for its control. The first application should be made as soon as the plants are up; a second application should be made a day or two before they are "pricked off." In some instances a third spraying before the plants go into the permanent beds may prove advantageous.

6. Proper ventilation and a dry foliage in periods of dark, cloudy weather are important in preventing the growth and spread of the disease. These operations must be coordinated with the control measures indicated above.

CONTROLLING DOWNY MILDEW OF LETTUCE

By A. T. Erwin

With the rapid development of the greenhouse industry in Iowa in the last decade, lettuce has become the most important vegetable crop grown under glass in this state. In some seasons a disease known as downy mildew is one of the most serious troubles met with in forcing this crop. Competition with garden lettuce from the Pacific Coast and the Gulf States, together with the high cost of production in recent years, makes the control of downy mildew an urgent question with many Iowa growers.

The downy mildew of lettuce, long known as a destructive garden and greenhouse disease, is caused by a parasitic fungus, *Bremia lactucae*, which is widely distributed in both Europe and America. It is somewhat similar to the fungus which causes rose mildew, and develops typical white, downy growths which are readily seen. These are found especially on the lower surface of the leaf. They consist of grayish masses of fungous growth, which produce myriads of spores, conidophores, by which the fungus is propagated.

Where the mildew persists, the affected plants in time take on a yellowish cast of green and become seriously stunted. With the arrest of growth the tissues lose their succulence and in severe cases the plants becomes worthless for salad purposes.

The first report of the occurrence of lettuce mildew in America, at least as to its being of economic importance, seems to be that of Farlow* in 1875. At that time he recorded it as becoming serious in the vicinity of Boston, which was the first commercial center for lettuce forcing in the United States.

The importance of this disease in Iowa was first brought to the attention of the writer in 1914 by Blackman Brothers, lettuce growers, at Nevada, Iowa, who reported that their winter crop had become so seriously stunted that it was unprofitable. An examination of beds containing half grown plants revealed a very general infection of mildew on the under surface of the leaves. From that time on the writer continued to give this disease more or less attention, but did not take up the study of it as a definite experiment station project until the fall of 1915.

The report on this project, which is herewith presented, has to do with the investigations as they centered upon the problem

* Bulletin Bussey Institution. Pages 427-1879.

ACKNOWLEDGMENT—In carrying forward these investigations, the writer was assisted by J. T. Rosa and F. E. McKune, graduate students in the years 1915 and 1916, respectively.

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of working out practical control measures. In this connection, those phases of the life history of the fungus which clearly have a bearing upon the successful management of lettuce crops under glass, have also been carefully considered.

DIFFERENCES IN SUSCEPTIBILITY OF LETTUCE TO MILDEW

One of the first questions of the grower is, do types and varieties of lettuce vary in susceptibility to downy mildew, and if so, to what extent? If important differences do exist, other things being equal, the first step along the line of control measures would be to select for planting only those varieties or types which are most resistant to the disease.

This subject was investigated from two different standpoints, (a) as to differences of varieties and classes or types of varieties in susceptibility to this disease and (b) as to the age or condition of growth of lettuce plants as related to their liability to infection by mildew.

(*a*) *Susceptibility of Classes and Varieties*:

Twenty-seven varieties of lettuce, representative of the loose leaf, the cos and the head lettuce types, were inoculated by the usual spore suspension method in the seedling stage. The plants were then placed in a moist chamber for 24 hours, thus subjecting them to conditions favorable to the growth of the fungus. Following this they were removed to open benches in the greenhouse. A statement of the results is given in table I.

The data indicate that the difference in susceptibility to mildew, if there is any, does not follow the line of the three main types or classes of lettuce. Varieties in all the groups are susceptible, and those belonging to the loose leaf type, such as the Grand Rapids and other leading commercial sorts, are subject to severe infection.

(*b*) *Age of Plants as Related to Infection*:

The question as to whether the plant is more susceptible to infection at one period of development than another was also

TABLE I—SUSCEPTIBILITY OF TYPES OF LETTUCE TO MILDEW

Variety	Date Inoculated	Date Inspected	Amount of Infection
Loose Leaf Type			
Black Seeded Simpson	March 9	March 15	Heavy
Grand Rapids	March 6	March 12	Very Heavy
Head Type			
Iceberg	March 9	March 15	Heavy
May King	March 6	March 12	Light
Hanson	March 9	March 15	Heavy
Prize Head	March 9	March 15	Light
Black Seeded Cutting	March 21	March 29	Very Heavy
Tennis Ball	March 21	March 29	Very Heavy
Cos Type			
Romaine	March 6	March 12	Heavy

investigated. A test was made with eighteen varieties, including representatives of the three classes of types, loose leaf, cos and head lettuce, in which the plants were inoculated with the mildew at the respective ages of 21, 31, and 45 days from the planting of the seed.

This experiment was made in a greenhouse which, being airy and well-lighted, did not offer conditions most favorable for the mildew. In order to make conditions more favorable for the development of the disease, the beds on which the plants were grown were converted into moist chambers by raising the sides 12 inches with boards and covering the tops with hotbed sash. Into these beds were transplanted the lot 3 plants, and to it were transferred the pots containing lots 1 and 2, immediately after the seedlings which they contained had been inoculated.

The seed was all sown in 12-inch pots, three pots for each variety under test. Shortly after germination, the seedlings were thinned to 100 to the pot. The plants for lots 1 and 2 were allowed to remain in the pots. The lot 3 plants were transplanted to a bed which had been converted into a moist chamber as above described, but they were not inoculated until after they had fully recovered normal condition of growth activities after being transplanted.

Lot 1 was inoculated at 21 days, lot 2 at 31 days and lot 3 at 45 days from planting. The comparative stages of development of the plants are indicated in fig. 1.

Fig. 1. Age of plants in relation to infection. Three lots as shown were inoculated with downy mildew. Lot 1 showed 90 percent infection, lot 2, 38 percent, and lot 3, 19 percent. These results emphasize the fact that downy mildew is primarily a seedling disease.

Six days after the respective inoculations, the plants were examined for mildew. The results are shown in table II.

TABLE II—PERCENTAGE OF MILDEWED LETTUCE PLANTS SIX DAYS AFTER INOCULATION AT 21, 31, AND 45 DAYS FROM PLANTING SEED

Variety	Percentage of Disease		
	Lot 1 (Inoculated 21 days after planting)	Lot 2 (Inoculated 31 days after planting)	Lot 3 (Inoculated 45 days after planting)
Loose Leaf Type			
Grand Rapids	96	55	1
Morse	93	62	6
Head Lettuce Type			
Iceberg	99	30	22
Hanson	51	58	9
Naumburger	86	17	22
Mignonette	100	45	36
Big Boston	81	67	33
Prize Head	96	48	15
Wheelers	83	13	45
Tomhannock	93	16	12
New Brittle Ice	100	59	2
Black Seeded Simpson	92	34	14
Early Curled Silicia	89	10	15
Yellow Seeded Butter	96	31	69
Cos Type			
Express	97	16	6
Trianon	88	33	3
Paris White	86	57	3
AVERAGE	90 Percent	38 Percent	19 Percent

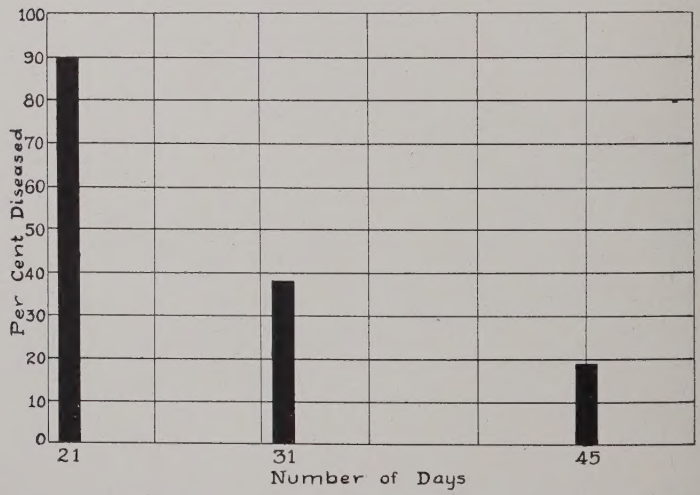

Fig. 2. Percentage of mildewed lettuce plants six days after inoculation at 21, 31, and 45 days, respectively, from planting of the seed.

A study of fig. 2 indicates clearly that the downy mildew of lettuce is distinctly a disease of the young seedling. The critical period for infection is when the plants are small, particularly at the age between the unfolding of the cotyledons and the expanding of the first true leaf. If the plants can be kept free from the mildew until they are half grown, the disease is of comparatively little importance so far as that crop is concerned. It may perhaps attack the lower leaves, which are more or less shaded and which come in contact with the moist earth but its presence is of little consequence.

On the other hand, in case the mildew gains a foothold on the young seedlings, the stunting effect on the young plant becomes very apparent by the time the plant is half grown. Such plants make only a slow growth and never recover. They have a stunted appearance and the upper surface of the lower leaves takes on a yellowish cast, indicating the presence of the mildew spots beneath.

WILD LETTUCE AND THE MILDEW

Wild lettuce is a coarse weed which is often found growing abundantly in neglected corners about the compost yard. In considering control measures, the question arises whether wild letuce is affected with downy mildew and, if so, whether it is the same species of mildew that grows on cultivated lettuce. If it is, wild lettuce in the vicinity might be an important source of infection for the greenhouse crop. Its eradication in such a case obviously would be the first step in preventing the disease.

Fig. 3. Wild Lettuce — *Lactuca scariola* — a plant which harbors downy mildew.

For the purpose of securing information upon this phase of the subject, wild lettuce plants were inoculated with spores of mildew taken from cultivated lettuce and, conversely, cultivated plants were inoculated with spores of the mildew from wild lettuce. On October 6, 1916, mildew was found upon cultivated lettuce in a cold frame at the college greenhouse. A few

days later mildew was also discovered in abundance upon young seedlings of wild lettuce. Spores taken from this material were used for the inoculation experiments above mentioned.

WILD LETTUCE INOCULATED WITH MILDEW FROM CULTIVATED LETTUCE

For the purpose of furnishing material for the inoculation tests, plants of different species of wild lettuce were grown under control conditions in the greenhouse from seed gathered from wild plants. When the seedlings were one inch high, they were inoculated with mildew from cultivated lettuce by the spore suspension method. Table III shows the results.

CULTIVATED LETTUCE INOCULATED WITH MILDEW FROM WILD LETTUCE

The plants of cultivated lettuce which were used in the inoculation experiments were grown in the greenhouse under control conditions. They were of two stages of growth, namely, small plants with the first true leaf developed and larger plants which were about half grown.

The small plants were held in a moist chamber described on page 309. The larger plants were benched and protected by a muslin cage from spores which might be floating in the air. The results are set forth in table IV.

A study of tables III and IV shows clearly that mildew of wild lettuce grows readily on cultivated lettuce and, conversely, the mildew of cultivated lettuce is readily propagated on wild lettuce.

It becomes evident that wild lettuce plants growing in the vicinity of greenhouses or frames where lettuce is being forced are a breeding ground for mildew, which may seriously injure or destroy the value of the crop. The first step in preventing

TABLE III—RESULTS OF INOCULATION OF WILD LETTUCE FROM CULTIVATED LETTUCE

Species of Lactuca	Date of Planting	Date of Inoculation	Date of Examination	Results
	Lot No. 1			
Lactuca scariola var. *integrata*	Oct. 7	Oct. 24	Oct. 30	Positive
Lactuca canadensis	Oct. 7	Oct. 24	Oct. 30	Positive
Lactuca sagittifolia	Oct. 7	Oct. 24	Oct. 30	Positive
Lactuca ludoviciana	Oct. 7	Oct. 24	Oct. 30	Positive
Grand Rapids (Check)	Oct. 7	Oct. 24	Oct. 30	Positive
	Lot No. 2			
Lactuca scariola var. *integrata*	Oct. 7	Nov. 3	Nov. 11	Positive
Lactuca canadensis	Oct. 7	Nov. 3	Nov. 11	Positive
Lactuca sagittifolia	Oct. 7	Nov. 3	Nov. 11	Positive
Lactuca ludoviciana	Oct. 7	Nov. 3	Nov. 11	Positive
Grand Rapids (Check)	Oct. 7	Nov. 3	Nov. 11	Positive

TABLE IV—RESULTS OF INOCULATION OF CULTIVATED LETTUCE FROM WILD LETTUCE

Variety of Lactuca	Test	Number of plants	Date of Planting	Date of Inoculation	Date of Examination	Results	
						Diseased	Not Diseased
Grand Rapids	(a)	30	Oct. 20	Nov. 3	Nov. 11	30	0
Scariola var. *integrata* (check)		10	Oct. 20	Nov. 3	Nov. 11	0	10
Grand Rapids	(b)	20	Oct. 20	Nov. 4	Nov. 12	20	0
Scariola var. *integrata* (check)		20	Oct. 20	Nov. 4	Nov. 12	15	5
Large Plants							
Grand Rapids	(c)	20	Sep. 25	Nov. 8	Nov. 14	12	8

lettuce mildew is, therefore, to destroy completely all wild lettuce plants in the vicinity.

DOES MILDEW WINTER OVER ON WILD LETTUCE?

The question as to how the downy mildew found on wild lettuce lives over winter in this region is one which has not yet been determined.

However, the following observations were made on this point. In the fall of 1916, just before the ground was frozen, areas on which fall seedlings of prickly lettuce, *Lactuca scariola*, were growing in large numbers, were marked. From one area, clumps of earth containing a considerable number of seedlings were lifted February 6 and transferred to the greenhouse. The seedlings survived the winter and made a vigorous growth.

Fig. 4. The stage of development at which *Lactuca scariola* carries over as a winter annual, is shown here.

This demonstrates that prickly lettuce, which has long been recognized as an annual, is also a winter annual in this region; that is to say, fall-sown seedlings survive the winter and complete their growth the following spring.

These observations are confirmed by other investigations. C. E. Durst, of the University of Illinois, writes under date of Feb-

ruary 15, 1919, that *Lactuca canadensis* and *Lactuca scariola* both act as winter annuals in that state.

In one of the areas above mentioned, 25 seedlings of wild lettuce on which mildew was found were staked before the ground froze, for observation. None of these plants, however, survived the winter.

It seems fair to assume that since some of the seedlings live thru the winter as winter annuals, the mildew which infests the species may possibly be carried over on some of the diseased plants. In the absence of resting spores, none having so far been discovered, it seems plausible to assume that the disease must carry over winter on live tissue. The fact that such is the case, however, has not yet been established.

INFECTION OF THE SOIL

The question as to whether garden and greenhouse soils may harbor the disease germs for any considerable period and thereby carry over the disease from one crop to another, is evidently of great importance as bearing upon methods of control. Many growers hold the opinion that lettuce mildew may get its start with a new crop, because the germs of the disease are in the soil.

Investigations bearing upon the question of infected soils were carried forward along these lines: (a) Comparison of the amount of mildew on lettuce following a diseased crop with that of a crop on new soil. (b) Effect of freezing upon the viability of mildew spores in the soil. (c) Disinfecting lettuce soils.

OLD SOIL VS. NEW SOIL

In the first test the variety Hanson was used. (1) Seed was sown in a seed pot on February 24, 1916, in soil from an infected bed. On March 13, when the first true leaves were fully developed, the pot was placed in a moist chamber to induce sporulation. The results were negative. (2) On May 1 two lots of seed were sown in pots. Lot 1 was sown in soil from a diseased bed into which diseased leaves were incorporated. Lot 2, the check, was sown in a virgin soil. Both lots were then placed in a cold frame. Lot 2 was placed under a bell jar to prevent aerial infection. By June 4, lot 1 showed heavy mildew infection and lot 2, the check, showed none. On June 9 the plants were carefully removed from the soil and lot 1 heavily re-seeded. The plants were shaded under a lath screen.

On July 20 these plants showed a heavy infection. No wild or cultivated plants were growing in the vicinity, thus removing the probability of aerial infection. It therefore seems evident

that the disease may carry over in the soil for at least a short period of time.

Lettuce houses are continually cropped, producing from four to five crops a year. The foregoing results suggest the necessity of sanitary measures, particularly in the removal of diseased leaves and other refuse, before re-spading the beds preparatory to replanting.

Precaution should also be exercised in bringing in new soil. Avoid a soil which is producing wild lettuce. In fact, it is wise to destroy all wild lettuce plants on the place before they seed. Wild lettuce is partial to a rich soil and is not uncommon around compost yards and on piles of decayed manure.

EFFECT OF FREEZING ON MILDEW SPORES IN SOIL

What is the effect of freezing upon the viability of mildew spores in the soil? Are *Bremea lactucae* spores destroyed by freezing and thawing? Can the gardner rid an infected soil from the lettuce bench by subjecting it to the elements of winter?

In the spring of 1916 one of the old cold frames at the college greenhouse was set with diseased plants. As the warm weather of summer came on, the disease disappeared. The frame was left idle and the soil maintained in a dry state during the summer. Early the following September it was sown to Grand Rapids and watered. On October 6, the first signs of downy mildew appeared. The plants were then heavily watered and very soon they became seriously infected with the disease. The bed was re-seeded and the disease remained abundant until the plants were killed by freezing.

The bed was then uncovered and subjected to severe freezing thruout the winter. The latter part of the following March the beds were again re-seeded to Grand Rapids, but the disease failed to make its appearance. Various extreme types of environment were tried, such as excessive watering, over-crowding and shading, so as to offer favorable conditions for mildew development. These efforts were without avail and the disease did not make its appearance at any time in the spring following the freezing of the soil.

Blackman Brothers, Nevada, Iowa, use cold frames extensively for lettuce growing in the spring. In the fall of 1916 the greater portion of the land to be devoted to frames was covered with manure to prevent the soil from freezing. The remaining area was left unprotected and the earth was subjected to severe freezing.

In the spring following, those areas receiving winter protection were planted first. The plants used came from the nursery greenhouse which had been free from the disease thruout the

winter and the plants had been sprayed twice before setting in the frames.

Soon after the plants had been placed in the protected frames downy mildew appeared, and shortly thereafter a large percentage of the plants became infected. Later, when the ground had thawed, those areas which had frozen up were also planted. These produced well and only a trace of the disease was found on these plants thruout the spring.

The evidence in the above instances suggests that the conidia of *Bremia lactucae* may survive in dry soil over summer, but are perhaps destroyed by severe winter temperatures.

DISINFECTING LETTUCE SOILS

In the way of disinfecting lettuce soils, the "drench method" was used. This requires three and one-half pints of formaldehyde to fifty gallons of water and is applied at the rate of one gallon to one square foot of surface. This method has been recommended for the control of downy mildew.*

The following experiment was conducted to determine the value of this treatment:

On February 16, 1917, eighteen 12-inch pots were filled with soil which had recently grown diseased lettuce.

Lot 1, consisting of nine pots, was saturated with formaldehyde solution, 1 to 30.

Lat 2, consisting of the remaining nine, was left untreated as a check plot.

Both lots were sown to Grand Rapids and lot 2 was placed in a separate compartment. The seed of both lots germinated promptly and there was no evidence of impaired germination from the formaldehyde. The seedlings were then thinned to 100 to each pot, or a total of 900 in each lot, to secure uniformity.

As soon as the cotyledons had fully developed, the plants were observed closely for symptoms of the disease. The results were as given in table V.

In the fall of 1914 the lettuce house of Blackman Brothers,

TABLE V—FORMALDEHYDE AS SOIL DISINFECTANT FOR CONTROL OF DOWNY MILDEW OF LETTUCE

Variety—Grand Rapids	Date Sown—March 15
Period under observation—March 28 to April 2	
Lot No.	Percent Infected
1	100
2	98

* Selby & Humbert, Ohio Agricultural Experiment Station, Circular No. 151-1915.

Nevada, Iowa, was treated with formaldehyde of a solution of 1 to 30. The beds are solid and it was aimed to saturate the soil spade depth, using one gallon to each square foot.

This house is used entirely for maturing the plants, the seedlings being handled up to the transplanting state in an adjacent house. The treated soil was set to lettuce early in September. By the middle of November the plants showed serious infection from downy mildew and before reaching maturity the entire crop became thoroly infected.

In both of these instances formaldehyde failed as a control measure. There can be no doubt as to the soil being disinfected in the first instance, as the soil was supersaturated.

Solid beds were used at the Blackman houses. Under these conditions there is always chance of turning up diseased soil from below in cultivating.

In any case, soil infection is only half the problem. Aerial infection must also be guarded against. Soil treatment alone will not succeed and is really one of the most difficult and expensive methods of control. Given a healthy soil to start with, spraying, general sanitation and the proper cultural relations are the more feasible methods of control.

STERILIZING BY HEAT

Sterilizing the soil by means of heat has also been recommended for the control of downy mildew of lettuce, the inverted pan and the perforated pipes being the methods suggested. Sterilizing by heat was included in the original outline of the experiment, but was not taken up, as it became evident in the progress of the work that aerial infection is the dominant factor with which we have to deal.

CONTROL MEASURES

Investigations concerning the control of lettuce mildew have been carried forward along these lines: (a) Spraying. (b) Fumigation. (c) Cultural Methods.

SPRAYING

The use of fungicides has had a wide application in general for the control of fungous diseases affecting garden crops, but, as far as we can learn, has not been used for controlling lettuce downy mildew. The fungicidal value of a number of spraying compounds which might be used has been clearly established, but there still remains the question as to their action upon the lettuce plant.

TABLE VI—EFFECT OF VARIOUS CHEMICALS ON LETTUCE PLANTS

Chemicals	Strength	Result on plants after two days
Ammoniacal copper carbonate	5 oz. copper carbonate; 3 pts. ammonia to 50 gallons water.	Almost dead
Ammoniacal copper carbonate	Double strength	Dead.
Ammoniacal copper carbonate	Half strength	Slightly burned
Potassium sulfide	3 oz. to 10 gals. water	Margin leaves burned
Potassium sulfide	Half strength	Leaves slightly burned
Soluble sulfur	1 oz. to 100 cc. water	Leaves somewhat burned
Copper sulfate	2 oz. per gal. water	Badly burned
Copper sulfate	1 oz. per gal. water	Almost dead
Copper sulfate	½ oz. per gal. water	Badly burned
Lime sulfur 32.09 Baume	4 parts to 100 of water	Leaves badly burned
Lime sulfur 32.09 Baume	2 parts to 100 of water	Leaves very slightly burned
Lime sulfur 32.09 Baume	1 part to 100 of water	Leaves uninjured
Nicotine sulfate (40%)	1 to 100 of water	Leaves slightly burned
Nicotine sulfate	1 to 300 of water	Very slightly burned
Nicotine sulfate	1 to 600 of water	Uninjured
Bordeaux mixture	4-4-50	Uninjured
Bordeaux mixture	5-4-50	Badly burned
Bordeaux mixture	6-4-50	Very badly burned
Bordeaux mixture	4-10-50	Uninjured

A large number of plants of the variety Grand Rapids in the intermediate stage of growth were sprayed with various chemicals. The results are indicated in table VI.

The following materials did not injure normal lettuce plants:

Lime sulfur	1 to 100
Nicotine sulfate (40%)	1 to 500
Bordeaux mixture	4-4-50

Investigation was made as to the relative value of different strengths of bordeaux mixture for control of mildew on lettuce seedlings. For this purpose Grand Rapids seedlings were started in pots. Just before the true leaves appeared the different lots were treated with bordeaux, as set forth in the following table. Two days after this treatment, all of the plants were sprayed with water in which an abundance of fresh mildew spores were in suspension. Examination after six days showed the results in table VII.

TABLE VII—SUSCEPTIBILITY OF LETTUCE SEEDLINGS TO *BREMIA LACTUCAE* WHEN SPRAYED WITH BORDEAUX

Variety—Grand Rapids. Date Sown—Jan. 14. Date sprayed with bordeaux —Feb. 2 Date inoculated—Feb. 4. Date examined—Feb. 11.

Strength of Mixture	Number of plants per pot	Leaves and cot	Leaves only	Cot only	Both cot sur.	Upper cot sur.	Lower cot sur.	Number of plants diseased	Number of plants not diseased	Percent of diseased plants
Check	106	0	0	98	95	0	3	98	8	92.4
2-2-50	138	0	0	10	2	0	8	10	128	7.3
4-4-50	92	0	0	8	6	0	2	8	86	8.2
6-6-50	120	0	0	20	14	0	6	20	100	8.5
8-8-50	118	0	0	22	4	0	18	22	98	8.6

TABLE VIII—AVERAGE PERCENTAGE OF DISEASED LETTUCE SEEDLINGS WHEN SPRAYED WITH DIFFERENT STRENGTHS OF BORDEAUX

	Strength of Mixture				
	Check	2-2-50	4-4-50	6-6-50	8-8-50
Percent	92.4	7.3	8.2	8.5	8.6

This experiment indicates that lettuce mildew may be readily controlled by bordeaux mixture of a strength of 2-2-50 and that nothing is gained by using a solution stronger than 4-4-50, which is the general formula for other garden crops.

Hanging drop cultures on glass slides were made of the conidia of *Bremia lactucae* in lime sulfur 1-100, nicotine sulfate (40 per cent) 1-1500, bordeaux mixture 4-4-50. In no case did any of the spores germinate.

Treatment of Young Seedlings With Bordeaux. An experiment was conducted to test the value of one treatment of bordeaux mixture as compared with two treatments. The varieties used in this test were Belmont, Tennis ball and Big Boston, which were growing in a cold frame. The bordeaux mixture was used at the strength of 4-4-50.

On March 12 when the first true leaves were just appearing, two flats of each of the varieties named were thoroly sprayed with bordeaux mixture. A week later one flat of each variety

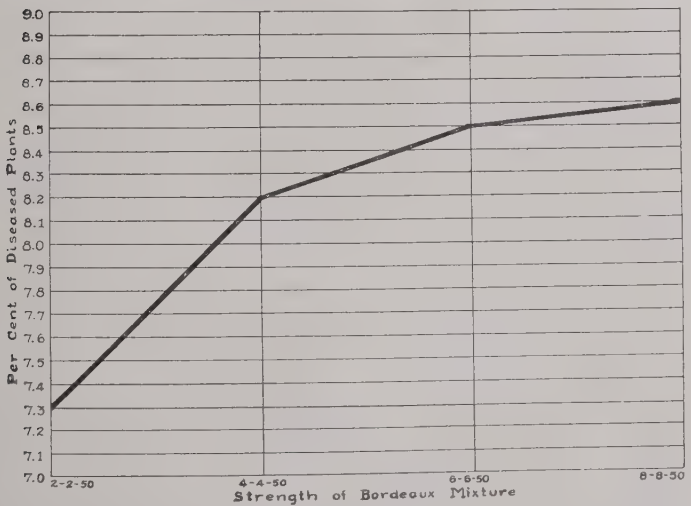

Fig. 5. This graph shows the percentage of diseased plants when sprayed with varying strengths of bordeaux mixture.

Fig. 6. These plants have reached the stage of development at which bordeaux mixture should be applied for control of downy mildew.

was given a second treatment. When the seedling had reached the proper stage for transplanting, those which had been sprayed once showed five percent infected with mildew, while those which had received two treatments showed less than 1 percent.

Treatment of Half-grown Seedlings with Bordeaux. In an experiment to test the value of bordeaux mixture after the plants were half grown, Grand Rapids plants were used. These were started in the usual way and transplanted to flats at the proper time and grown in a cold frame. There were 40 flats, making a total of 4,000 plants used in the test. Diseased plants were introduced and this lot became badly mildewed. Three flats were then removed to a corresponding frame, where they were held as a check. The plants in the other 37 flats were then thoroly sprayed with bordeaux mixture.

An inspection made one week following this treatment showed 35 percent of the treated plants infected with the mildew and 72 percent of the untreated. A very important feature of the results is not indicated in these figures. The sprayed plants, which before treatment were showing a good deal of the unhealthy color characteristic of mildewed lettuce, had regained normal color and grown to a considerable degree. Eventually these developed solid heads. The unsprayed plants, on the other hand, developed very slowly and for the most part were lacking in succulence and quality.

Transplanting Bordeaux-treated Lettuce Seedlings. It has been observed by some commercial growers that when lettuce plants are sprayed with bordeaux shortly after transplanting, they show an unusual amount of wilting. Duggar's investigations have a bearing on this point.* He shows that with potato foliage for a period of two to three hours following the application of bordeaux mixture, the rate of loss of water by transpiration was doubled. It appears, therefore, inadvisable to spray seedlings with bordeaux either immediately before or after transplanting. It has been the observation of the writer, however, that if bordeaux treatment is delayed until a day or two after transplanting, no apparent wilting follows.

FUMIGATION AS A CONTROL MEASURE

Fumigation with sulfur for the control of various kinds of downy mildew has been repeatedly recommended in popular garden literature. In the control of rose mildew, sulfur is commonly applied, either directly or with lime, to greenhouse pipes. Experiments were conducted to determine the efficiency of fumigation with sulfur in this way for the control of lettuce mildew and also to determine the amount of time the lettuce may be subjected to sulfur fumes without injury.

Sulfur fumes were generated by vaporizing sulfur on a sand bath heated by a small kerosene stove. The heat was regulated to vaporize the sulfur, but not ignite it. Various lots of seedling plants were placed in a wardian case and exposed to sulfur fumes for different periods, as indicated in the table.

Spores taken from the treated plant were then tested in the usual way for germination. This experiment was repeated three times. The following table shows the average of the three tests.

Since in these tests it requires over 30 minutes to kill all the spores, and exposure beyond 15 minutes resulted in injury to the plants, which varied from slight to more and more severe injury, as the length of the exposure was increased, and since

TABLE IX.—EFFECT OF SULFUR FUMIGATION ON LETTUCE DOWNY MILDEW

Amount of sulfur used per cubic foot—½ gram		
Time Exposed	Germination of Spores after Treatment	Effect on Plant
15 min.	13 percent	No injury
20 min.	4 percent	Slight injury
30 min.	3 percent	Severe burning
40 min.	0 percent	Severe burning
60 min.	0 percent	Very severe burning

* Mo. Bot. Garden. 1:1-22:351-356.

the conditions of these tests no doubt represent fairly well the average conditions under which the work would need to be done, it appears that the problem of controlling lettuce mildew by fumigating with sulfur is not an easy one. From the standpoint of the commercial grower, it is evident that less risky and more reliable methods are needed.

A single illustration taken from the experience of a commercial grower proves this point. On the night of March 11, 1916, Blackman Brothers, of Nevada, Iowa, fumigated the lettuce house with sulfur, using 12 ounces per 1000 cubic feet. The mildew present on the surface was destroyed, every trace of it being removed. The plants were severely burned, about 30 percent of them beyond recovery. The remainder were set back two weeks in their development.

Humidity in Fumigation. As noted above, the serious problem in the use of sulfur for fumigation is not to kill the spores, but to avoid injuring the plants. The amount of moisture in the atmosphere is an important factor in this regard, as is indicated in the results given in table X.

It will be noted that in this case, with only one-half the amount of sulfur used in the previous experiment, but with a high humidity, there was severe burning even in ten minutes. The degree of humidity is evidently an important factor in determining the strength and time of exposure the lettuce will stand without injury. Special precautions should be taken to secure a dry atmosphere if sulfur fumigation is used.

Re-infection of Fumigated Plants. The efficiency of fumigation is determined largely by the time elapsing before re-infection. On the plants treated up to fifteen minutes, re-infection developed within a week. Re-infection did not take place on the lots treated over fifteen minutes under greenhouse conditions. It did appear, however, in a mild form on these lots when the plants were placed in a moist chamber. On the whole, sulfur fumigation does not appear promising as a control measure. In badly infested houses it can be used to advantage as a sanitary measure for cleaning up the houses while vacant.

TABLE X.—INFLUENCE OF HUMIDITY IN FUMIGATING UPON LETTUCE PLANTS

In which ¼ gram per cubic foot was used in a chamber containing 91 percent humidity

Time Exposed	Percent Germination of Spores after Treatment	Effect on Plants
10 min.	15 percent	Severe burning
15 min.	3 percent	Severe burning
20 min.	2 percent	Very severe burning
25 min.	0 percent	Dead
40 min.	0 percent	Dead

CULTURAL METHODS

A number of cultural factors have a direct bearing upon the control of downy mildew: (1) Watering, either sub-irrigation, or overhead irrigation; (2) Ventilation; (3) Humidity; (4) Temperature; (5) Sunlight.

(1) *Watering.* In the experimental work with downy mildew of lettuce, special attention was given to two methods of watering in relation to the control of the disease, namely, sub-irrigation and overhead irrigation. At Blackman Brothers' greenhouses all the seedling lettuce plants were watered by irrigation.

Sub-irrigation: The nursery greenhouse is 22x125 feet and is supplied with concrete water pans 12x16 feet, 4 inches deep. The newly potted plants are placed in these. In watering, the pans are filled with water about one-fourth of an inch deep. After the soil has become saturated, the surplus is drained off. The plants are so handled until they are transplanted into the permanent bed. Seed flats are handled in the same manner. By this method the plants were provided with full ventilation and the foliage kept dry, which added to the efficiency of the bordeaux applications. The even spacing of the plants aided in securing a thoro application of the spray mixture. Each succeeding crop of seedlings in the nursery house was given two applications of bordeaux. Despite the fact that downy mildew is primarily a seedling disease, there were no symptoms of this malady in the nursery house thruout the season. The bordeaux applications and the method of handling the plants contributed to this end.

Overhead irrigation: At Blackman Brothers, a house 50x150 feet was equipped with an overhead irrigating system. This has solid benches and was used to grow plants transplanted from thumb pots to a marketable size. Whenever the plants were in need of water they were given a thoro soaking by means of overhead sprinkling.

Early in February, 1917, a few of the large plants were found infected with Bremia. This disease remained active during the remainder of the forcing season. During January and February, sunless days are the rule and transpiration is therefore at a minimum, consequently the air remained humid and the foliage, due to the crowding condition of the plants, remained wet for days at a time. It is needless to add that these conditions created an ideal environment for the growth of downy mildew.

Overhead watering is a great convenience and economizes labor, but the advisability of its use during the sunless period

of winter may be seriously questioned where the control of downy mildew is a problem. Particularly on the larger plants, the hose is to be preferred in dark weather. In this way the surface can be flooded without seriously wetting down the foliage. Care should be exercised to see that the force of the stream is reduced to a gentle flow, in order that the soil may not be washed away from the roots.

(*2*) *Ventilation*: The growers of the state have various ideas as to the effect that ventilation has upon Bremia. The majority, however, feel that the lettuce should be given plenty of fresh air. For the purpose of determining just what effect ventilation has upon Bremia, a number of observations were made as follows:

Ventilation of cold frames: Blackman Brothers operate a large number of lettuce cold frames. It is the practice of these growers to ventilate whenever possible. This was done by sliding the sash toward the lower end of the frame, leaving an opening of a few inches at the upper end of the frame for ventilation.

Soon after the plants were set in the cold frames in the spring of 1917, they became infected with Bremia. The disease first appeared on the plants on the upper side of the frames and directly under the openings. The surrounding plants became infected later. During the entire season the plants that received the most ventilation showed the heaviest infection. In a frame there is very little overhead space, consequently the plants nearest the openings are likely to be severely chilled and are also the most subject to aerial infection. As with roses and other greenhouse crops, it is a recognized fact that plants subjected to a cold draft and extreme variations in temperature are most likely to become mildewed.

In general, it may be said that ventilation is an important factor in the control of downy mildew. Wide, high houses which provide a liberal overhead space, protect the plant from sudden changes in temperature and chilling and admit a free circulation of tempered air, are a great advantage from this standpoint.

(*3*) *Humidity*: A number of plants of both the wild and cultivated lettuce growing in a wardian case in the spring of 1917 showed a light infection of downy mildew. These plants were moved to a sunny house and given a liberal spacing and mildew had disappeared. A number of the plants were then freely ventilated. Within two days all visible evidences of the placed under a bell jar and heavily shaded. Within 24 hours the fruiting spores re-appeared in great abundance. This ex-

periment was repeated a number of times with the same result. It emphasizes the fact that ventilation and sunshine are contributing factors towards holding the disease in check.

Lettuce, like most plants, does best in a moderately humid atmosphere. In combating mildew it may be necessary to reduce temporarily the humidity of the greenhouse during periods of dark weather.

(*4*) *Temperature*: The best temperature for the germination of the conidia has been determined by studies made in the laboratory. In order to check these results under greenhouse conditions the following experiment was conducted:

A batch of transplants of Grand Rapids variety was divided into two lots of 250 plants each. They were then infected with mildew by the spore-suspension method. After the disease had become well established, the lots were placed in separate compartments and subjected until half-grown at the night temperatures indicated in table XI.

Lot 1 was grown under what many growers regard as the most desirable temperatures for leaf lettuce. Forty-five degrees Fahr. was formerly regarded as the best night temperature for leaf lettuce. However, it seems probable that in the control of mildew, at least 3° Fahr. higher can be used to advantage and that the maturity of the crop can be hastened thereby.

(*5*) *Sunlight*: In the spring of 1917, 250 half-grown lettuce plants were sprayed with a spore suspension of Bremia lactuca. Of these plants 180 were left exposed to the ordinary lettuce house conditions. The remaining 70, in the same house, were shaded with hot-bed cloth. In the purse of seven days only one plant of the 180 showed infection, while 17 of the shaded plants showed a heavy infection.

The influence of sunlight upon the growth of this organism was strikingly illustrated in our work at Ames. The College operates two separate ranges of glass. The one represents the old type of low, narrow houses with small panes of glass, which are poorly lighted and in which the temperature fluctuations are extreme.

In the new range, the gutters are high and the houses well lighted. In conducting mildew experiments, it was found to be rather a simple matter to perpetuate the disease in the old

TABLE XI.—TEMPERATURE RELATION TO INFECTION WITH BREMIA LACTUCAE

Temperature	Results
Lot 1—48 to 52° Fahr.	Sporulation very abundant
Lot 2—55 to 72° Fahr.	Infection light on lower surface only

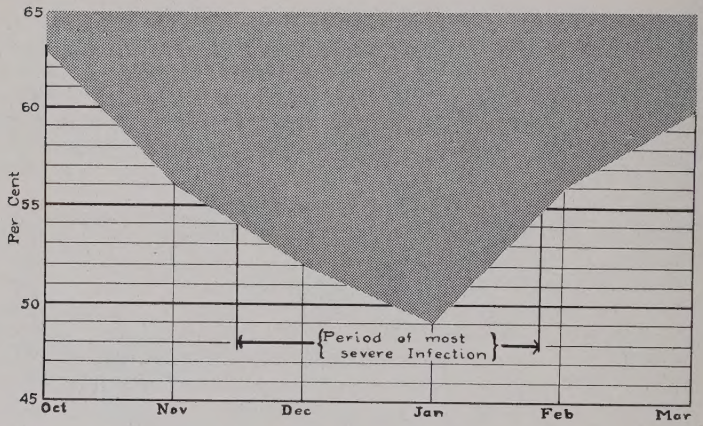

Fig. 7. The darkened area indicates the percentage of cloudiness and the white section the proportion of sunshine during the daylight hours for the months named.

houses and an equally difficult one to promote its growth in the new vegetable house.

The outstanding difference between the two ranges was primarily sun exposure. The period of the year at which lettuce mildew is most likely to make its appearance is also significant in this connection.

As will be noted by fig. 7, the period of minimum sunshine and mildew infection under glass are closely correlated. The climatic relationship from the standpoint of sunshine hours is therefore an important one.

FLATS vs. POTS FOR LETTUCE SEEDLINGS

Lettuce plants are commonly grown in seed flats to the proper size for transplanting into the beds. The seed is sown in flats and as the first true leaf begins to appear, the seedlings are pricked off and reset in flats, the plants being spaced about two inches apart each way. After the second or third true leaf appears, they are transplanted to the permanent beds.

Having in mind the fact that downy mildew is primarily a seedling disease and that the plants in the flats often become so crowded as to encourage disease, and also that the plants so handled are checked more or less in the final transplanting, Blackman Brothers adopted the plan of transplanting into thumb pots instead of flats and from the pots to the benches.

In order to compare the value of these two methods from the standpoint of disease control and the relative time required to

mature the crop, the following experiment was conducted in cooperation with Blackman Brothers:

Two lots of Grand Rapids of 500 plants each were grown in the spring of 1917. In lot 1 the seedlings were potted off into thumb pots before the first true leaf appeared. Lot 2 was transplanted to the beds after the second true leaf appeared. Table XII gives a summary of the results, including the comparative cost.

The spraying of plants, particularly the under surface of the leaves, was done much more thoroly on the pot plants. The plants had a better exposure to the air and sunlight, and were more stocky.

The flat grown plants were ready for the final transplanting six days earlier than the pot plants. The flat grown plants were much more severely checked at the final transplanting and never caught up with the pot grown plants after being set in the beds.

The pot grown plants were scarcely checked at all by the final transplanting and reached a marketable size a week in advance of lot 2. The growing of plants in pots, on a basis of 25 cents per hour for labor, entails an added cost of approximately 50 cents per thousand.

A GROWER'S EXPERIENCE WITH DOWNY MILDEW

A large part of this investigation dealing with control measures has been conducted at the greenhouses of Blackman Brothers, Nevada, Iowa.

TABLE XII.—POT-GROWN SEEDLINGS VS. FLATS

Number of plants in each lot—500

	Lot 1 : Pots			Lot 2 : Flats		
	Date	No. of man hours	Remarks	Date	No. of man hours	Remarks
Seed sowing	Jan. 19			Jan. 19		
First transplanting	Jan. 31	2 hours 10 min.	No set-backs; plants thrifty	Jan. 31	1 hour 40 min.	No set-backs; plants thrifty
Final transplanting	Feb. 21	2 hours	No set-back from transplanting	Feb. 15	1 hour 30 min.	Plants larger than potted plants, but on transplanting took on a withered appearance. Lower leaves yellowed. Died
Harvested	Apr. 6			Apr. 13		
Total labor time		4 hours 10 min.			3 hours 10 min.	
Comparative cost per 1000 at 25c per hour.						

Under date of February 15, 1919, Mr. Blackman gives the following report, summarizing his experiences in the control of downy mildew of lettuce.

After growing lettuce for many years, our lettuce crop became infected during the winter of 1912 and 1913, causing us severe losses for four years before we entirely overcame the disease.

We tried changing the soil, sterlizing with formaldehyde, spraying with bordeaux, fumigating with sulfur, all to no purpose. Formalin proved entirely useless for mildew. We were finally successful in the following treatment, which was recommended by the Iowa Experiment Station:

Before starting operations in the fall we took all the soil out of our plant house, washed all walks and benches with water thru the hose, closed the house tightly and fumigated heavily with sulfur.

We then brought in new soil, sowed seed in flats, and, as soon as the plants were out of the soil, sprayed them well with bordeaux, 4-4-50, and again a day or two before pricking out.

In spraying, great care was used to spray from all sides so as to cover under sides of leaves. We have found no further spraying necessary. We have not had one affected plant, either last winter or so far this season.

The secret of the whole matter is to spray the plants while very young. If you preserve the seed leaf, you have forestalled the disease. The fumigation may not be necessary, but we did this as a matter of precaution. It took two years of this treatment to get rid of the disease, altho it was effective at the first trial.

We cannot agree that heat is conducive to the development of downy mildew. Our experience showed that a close, cool and damp atmosphere is ideal for its rapid growth, while more fire heat and more ventilation, with a consequently dryer atmosphere, will tend to lessen its effects. We have placed affected plants over hot water pipes in a tomato temperature and they grew away from the disease, while other plants in cold frames in March would be eaten up with mildew.

We found in transplanting to permanent beds that the large plants were lacking in vitality and would sometimes be two weeks or more getting a new start. We then grew the plants in 2½-inch pots and could keep them growing right along. We liked this plan so well that we now grow them that way, altho we are rid of the mildew. While the plan is more expensive, a much more even crop can be grown and in several days less time.